

**Listing of Claims:**

This listing of claims will replace all prior versions and listings of claims in the application:

1. (Currently Amended) A system for estimating the position, velocity and orientation of a vehicle, comprising:

- ~~means for determining the components of two noncollinear constant unit vectors  $\hat{g}_b, \hat{e}_b$  according to vehicle body axes, said means including:~~

- an Inertial Measurement Unit (IMU) including a group of at least three gyroscopes for measuring the angular velocity  $\hat{\omega}_b(t)$  of the vehicle in body axes and at least three accelerometers located along the vehicle body axes to provide the specific force  $\hat{a}_b$  in body axes;

- a magnetometer able to measure the Earth's magnetic field according to the vehicle body axes;

- static pressure and differential pressure sensors;

- two vanes to measure the angles of attack and side slip;

- an angular velocity acquisition and processing module configured to acquire the angular velocity  $\hat{\omega}_b(t)$  and delay it to obtain  $\hat{\omega}_b(t - \tau)$ ;

- a data acquisition and processing module configured to acquire the specific force  $\hat{a}_b(t)$  measured by the accelerometers, the static pressure  $\hat{p}_s(t)$  measured in sensor, the differential pressure  $\hat{p}_d(t)$  measured in sensor, the angle of attack  $\hat{\alpha}(t)$  measured in sensor, the angle of sideslip  $\hat{\beta}(t)$  measured in sensor and the value of the Earth's magnetic field  $\hat{m}_b(t)$  measured in the magnetometer, delay them and process them to calculate the true airspeed  $\hat{v}(t - \tau)$ , the air velocity in body axes  $\hat{v}_b(t - \tau)$  as follows:

$$\hat{v}_b = \begin{bmatrix} \hat{v} \cos \hat{\alpha} \cos \hat{\beta} \\ \hat{v} \sin \hat{\beta} \\ \hat{v} \sin \hat{\alpha} \cos \hat{\beta} \end{bmatrix},$$

the numerical derivative of the air velocity in body axes  $\dot{\hat{v}}_b(t-\tau)$ ,

the local gravity in body axes  $\hat{g}_b$  as follows:

$$\hat{g}_b(t-\tau) = \dot{\hat{v}}_b(t-\tau) + \hat{\omega}_b(t-\tau) \times \hat{v}_b(t-\tau) - \hat{a}_b(t-\tau)$$

and the projection of the Earth's magnetic field on the horizontal plane perpendicular to local gravity  $\hat{e}(t-\tau)$  as follows:

$$\hat{e}_b(t-\tau) = \hat{m}_b(t-\tau) - \hat{m}_b(t-\tau) \cdot \frac{\hat{g}_b(t-\tau)}{|\hat{g}_b(t-\tau)|};$$

- a GPS receiver for determining the components of ~~said two~~ noncollinear constant unit vectors  $\vec{g}_t, \vec{e}_t$  according to the Earth's axes; wherein the data provided by the GPS are acquired, processed and used in the data acquisition and processing module to calculate said components  $\vec{g}_t, \vec{e}_t$ ;

~~wherein the system comprises~~

- a module for correcting said angular velocity  $\hat{\omega}_b$  with a correction  $u_\omega$  and obtaining a corrected angular velocity  $\hat{\omega}_b = \hat{\omega}_b + u_\omega$ ;
- a module for integrating the kinematic equations of the vehicle receiving the corrected angular velocity  $\hat{\omega}_b$  as input and providing the transformation matrix  $\hat{B}$  for transforming Earth's axes into vehicle body axes and the orientation of the vehicle in the form of Euler angles  $\hat{\Phi}$ ;
- a synthesis module of the components in body axes of the two noncollinear constant unit vectors to provide an estimation of said noncollinear vectors in body axes  $\hat{g}_b, \hat{e}_b$ , where said estimation is calculated as follows:

$$\begin{aligned} \vec{g}_b &= B\vec{g}_t \\ \vec{e}_b &= B\vec{e}_t \end{aligned}$$

- a control module implementing a control law to calculate said correction  $u_\omega$ , where said control law is:

$$u_{\omega} = \sigma(\hat{g}_b \times \hat{g}_b + \hat{e}_b \times \hat{e}_b) \quad [1]$$

where  $\sigma$  is a positive scalar,

such that by applying this correction  $u_{\omega}$  to the measured angular velocity  $\hat{\omega}_b$  and using the resulting angular velocity  $\hat{\omega}_b = \hat{\omega}_b + u_{\omega}$  as input to the module for integrating the kinematic equations, the latter are stable in the ISS sense and the error in the estimation of the direction cosine matrix  $\hat{B}$  and of the Euler angles  $\hat{\Phi}$  is bounded.

2. (Previously Presented) The system according to claim 1, wherein said noncollinear unit vectors  $\vec{g}, \vec{e}$  are local gravity  $\vec{g}$  and projection of the magnetic field on the plane perpendicular to gravity  $\vec{e}$ .

3 – 4. (Canceled)

5. (Currently Amended) The system according to claim 1, further comprising ~~wherein the system includes a~~ Savitzky-Golay filter where  $\dot{\hat{v}}_b$ , numerical derivative of  $\hat{v}_b$ , is calculated.

6. (Currently Amended) The system according to claim 1, further comprising including:

- a navigation module where the navigation equations of the vehicle are integrated from the specific force  $\hat{a}_b$  and the direction cosine matrix  $\hat{B}$  to obtain calculated position and velocity in local axes and corrected in a Kalman filter to obtain estimated position and velocity in local axes.

7. (Previously Presented) A method for estimating the position, velocity and orientation of a vehicle comprising:

- calculating the components of two noncollinear constant unit vectors  $\hat{g}_b, \hat{e}_b$  according to vehicle body axes from measurements of sensors located in the

vehicle according to the body axes of the latter, said calculation comprising:

- measuring specific force  $\hat{a}_b(t)$  in body axes, static pressure  $\hat{p}_s(t)$ , differential pressure  $\hat{p}_d(t)$ , angle of attack  $\hat{\alpha}(t)$ , angle of sideslip  $\hat{\beta}(t)$  and the value of the Earth's magnetic field  $\hat{m}_b(t)$ ;

- calculating the true airspeed  $\hat{v}(t)$  from the differential pressure  $\hat{p}_d(t)$  and static pressure  $\hat{p}_s(t)$  measurements and from knowing the outside temperature at the initial moment  $T_0$ ;

- calculating the air velocity in body axes as follows:

$$\hat{v}_b = \begin{bmatrix} \hat{v} \cos \hat{\alpha} \cos \hat{\beta} \\ \hat{v} \sin \hat{\beta} \\ \hat{v} \sin \hat{\alpha} \cos \hat{\beta} \end{bmatrix};$$

- delaying a time  $\tau$  the angular velocity  $\hat{\omega}_b(t)$ , specific force  $\hat{a}_b(t)$ , magnetic field  $\hat{m}_b(t)$  and air velocity in body axes  $\hat{v}_b(t)$ ;

- calculating the numerical derivative of the air velocity in body axes  $\dot{\hat{v}}_b(t-\tau)$ ;

- calculating the local gravity in body axes  $\hat{g}_b$  as follows:

$$\hat{g}_b(t-\tau) = \dot{\hat{v}}_b(t-\tau) + \hat{\omega}_b(t-\tau) \times \hat{v}_b(t-\tau) - \hat{a}_b(t-\tau); y,$$

- calculating the projection of the Earth's magnetic field on the horizontal plane perpendicular to local gravity as follows:

$$\hat{e}_b(t-\tau) = \hat{m}_b(t-\tau) - \hat{m}_b(t-\tau) \cdot \frac{\hat{g}_b(t-\tau)}{|\hat{g}_b(t-\tau)|};$$

- calculating the components of said noncollinear constant unit vectors  $\hat{g}_t, \hat{e}_t$ , according to the Earth's axes from measurements of sensors located in the vehicle which provide position in Earth-fixed axes;
- measuring the three components of angular velocity  $\hat{\omega}_b$  of the vehicle in body axes;
- correcting the angular velocity  $\hat{\omega}_b$  with a correction  $u_\omega$  and obtaining a

corrected angular velocity  $\hat{\omega}_b = \hat{\omega}_b + u_\omega$ ;

- integrating the kinematic equations of the vehicle, according to the corrected angular velocity  $\hat{\omega}_b$  and providing the transformation matrix  $\hat{B}$  for transforming the Earth's axes into vehicle body axes and the orientation of the vehicle in the form of Euler angles  $\hat{\Phi}$ ;
- calculating an estimation of the components in body axes of the two noncollinear constant unit vectors  $\hat{g}_b, \hat{e}_b$ , where said estimation is calculated as follows:

$$\begin{aligned}\hat{g}_b &= \hat{B}\vec{g}_t \\ \hat{e}_b &= \hat{B}\vec{e}_t\end{aligned}$$

- obtaining the correction  $u_\omega$  by means of the control law:

$$u_\omega = \sigma(\hat{g}_b \times \hat{g}_b + \hat{e}_b \times \hat{e}_b) \quad [1]$$

where  $\sigma$  is a positive scalar,

such that upon applying this correction  $u_\omega$  to the measured angular velocity  $\hat{\omega}_b$  and using the resulting angular velocity  $\hat{\omega}_b = \hat{\omega}_b + u_\omega$  as input to the module for integrating the kinematic equations, the latter are stable in the ISS sense and the error in the estimation of the direction cosine matrix  $\hat{B}$  and of the Euler angles  $\hat{\Phi}$  is bounded.

8. (Previously Presented) The method according to claim 7, wherein said noncollinear unit vectors  $\vec{g}, \vec{e}$  are local gravity  $\vec{g}$  and projection of the magnetic field on the plane perpendicular to gravity  $\vec{e}$ .

9 – 10. (Canceled).

11. (Previously Presented) The method according to claim 7, wherein  $\dot{\hat{v}}_b$ , the numerical derivative of  $\hat{v}_b$ , is calculated in a Savitzky-Golay filter.

12. (Previously Presented) A method according to claim 7 including:
  - integrating the navigation equations of the vehicle according to the specific force  $\hat{a}_b$  and the direction cosine matrix  $\hat{B}$  to obtain the calculated position and velocity in local axes and they are corrected in a Kalman filter to obtain estimated position and velocity in local axes.